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13. ABSTRACT *(Maximum 200 words)*
This report summarizes findings relative to the suitability of the Method of Smoothing to the prediction of scattering from randomly rough surfaces. It also outlines the method called the Method of Ordered Multiple Interaction (MOMI) for reducing storage and running time requirements.

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Rough Surface Scattering Studies Using the Method of Smoothing

FINAL PROGRESS REPORT

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31 May 1996

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INVESTIGATION TITLE: Rough Surface Scattering Using the Method of Smoothing
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PROBLEM, MOST IMPORTANT RESULTS, AND SUMMARY:

The purpose of this investigation was to determine the extent to which the Method of Smoothing (MoS) could aid in the understanding and analysis of scattering from randomly rough extended surfaces. The way we have developed it, the Method of Smoothing splits the product of the current (induced on a rough pec surface) and an exponential phase factor (that depends on the surface height and the scattering angle) into a sum of a mean value and a zero mean fluctuating value. Substituting this representation back into the governing equation for the surface current results in two coupled integral equations, one for the mean product and the other for the fluctuating product. However, the form of the mean product is know a priori due to the specular nature of the mean scattered field; the only part of this unknown that is to be determined is its amplitude. The resulting integral equation for the fluctuating product is of the second kind and, in principle, can be solved by iteration. The Born term, or first iterate, was of most interest to us because it required the least amount of work to evaluate.

We were able to determine that MoS worked best when large scale gently undulating surface features were normalized out of the basic integral equation prior to the application of MoS. This was accomplished by dividing the integral equation by the large scale part of the incident phase factor. In this way it was possible to isolate the effects of the small scale fluctuating and mean parts of the surface. Using this approach, we were able to give a more rigorous foundation to the so-called composite scattering theory. Furthermore, we could show that the way to improve on the Born approximation was to set up a sequence of integrals whose support on the surface encompassed increasingly larger areas about the point in question. When the multiple scattering on the surface was small, it was necessary to take only one of the integrals. As the degree of multiple scattering increased, more and more of these integrals were required.

Thus, the MoS contained a great deal of insight into the complex scattering processes that take place on the surface. Unfortunately, its primary drawback to the use of MoS was the complexity of the integrals that needed to be evaluated to get numbers from the method! Although we able to do some limited calculations with the method, we did not think that it could be a viable method for solving two-dimensional roughness problems.

This caused us examine an idea that was first suggested by Dennis Holliday and his group at Logicon-RDA. The idea was to split the propagator in the basic integral equation into the sum of a part that accounted for all surface multiple scattering coming from the left of the point of observation and a part that accounted for similar multiple scattering coming from the right. Holliday recognized that such a splitting could be used to form two coupled integral equations of the first kind that could be much more easily solved that the original equation. He called his new approach "a forward-backward approach". Almost in parallel with his efforts we developed a very similar solution based on recognizing that the "left-side or forward" propagator could be represented as a lower triangular matrix while the "right-side or backward" propagator could be represented as a upper triangular matrix when the basic integral equation was discretized for solution by moment-type methods. It turned out that by recognizing this particular propagator matrix decomposition, the current integral equation could be solved without inverting a matrix. Furthermore, the computation went much faster, e.g., by a factor of N where N is the number of points on the surface where the current is sampled.

Calculations using this new numerical technique showed that it was both robust and fast and represented a significant improvement over the conventional Method of Moments approach.

LIST OF PUBLICATIONS:

Kapp, D.A. & G.S. Brown,"Effect of correlation between shadowing and shadowed points in rough surface scattering," *IEEE Trans. Antennas & Propagation*, Vol. **42**, pp. 1154-1160, 1994.

Abstract— **The effect of correlation between shadowing and shadowed points upon various shadowing functions is studied. The backscatter (monostatic) shadowing function for a two-dimensional perfect electric conducting surface is calculated by modifying an infinite series representation developed by Ricciardi and Sato. It is shown that when correlation between all shadowing and shadowed points is neglected in the series the result reduces to one of the shadowing functions purposed by Wagner. This is useful since it explains from a physical point of view one of the assumptions made by Wagner, which was necessary to obtain the closed form result. We further calculate the shadowing function with correlation included by considering the first three terms in the modified Ricciardi–Sato series. These terms provide an upper and lower bound to the exact shadowing function. We show the effect of neglecting the higher order terms by relating them to the number of intersections of the surface with the incoming rays. Finally, we present results that show that the shadowing function purposed by Smith overestimates the effect of shadowing due to the neglect of correlation between the shadowing and shadowed point and a normalization term. Importantly, we also show that the shadowing function derived by Wagner, which attempts to include the effect of this correlation, does not produce an improved result.**

D.A. Kapp & G.S. Brown,"A new numerical method for rough-surface scattering calculations," *IEEE Trans. Antennas & Propagation*, Vol. 44, pp. 711-721, 1996.

***Abstract*—A new approach to solving the magnetic field integral equation (MFIE) for the current induced on a infinite perfectly conducting rough surface is presented. By splitting the propagator matrix into contributions from the left and from the right of the point of observation, a second kind integral equation can be formed with a new Born term and a new kernel. Following discretization of this new integral equation, the unknown currents can be determined more rapidly and with significantly less storage requirements than conventional LU decomposition; where the time saving factor is roughly $N/3$ where N is the number of current samples on the surface and the usual storage requirements associated with matrix inversion are eliminated. While the new Born term is usually adequate for scattered field calculations, the new discretized integral equation can be iterated to any desired accuracy with no apparent convergence problems. Results are presented for one-dimensional rough surfaces with rms heights exceeding one wavelength and rms slopes exceeding 40° which illustrate the robustness of the new Born term.**

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INVENTIONS: None
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